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PRICING FOR WATER SUPPLY: ITS IMPACT ON SYSTEMS MANAGEMENT

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Problems related to water supply have become increasingly important in recent years. In the past, water has been so abundant that it was available in almost unlimited quantities. But this is no longer the case in many parts of the United States. Water has become a resource that is relatively scarce. And the land, labor, and capital resources needed to convey water to places of useful application and to collect and treat wastewater are also scarce.

This paper discusses current pricing policies by water utilities and the changes in consumption patterns which other investigators have found resulting from the changes in price for water supplies. Water consumption and pricing data are analyzed for a specific SMSA. The potential impact of pricing policies on technology and wastewater reuse is discussed.

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PRICING FOR WATER SUPPLY; ITS IMPACT ON SYSTEMS MANAGEMENT

by

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Program Element No. 1CA046

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

This report examines the costs associated with supplying drinking water to consumers and their reaction in terms of increased or decreased consumption based on the prices which they must pay. It also explores the relationship of drinking water quality to cost and suggests the possibility of using the pricing mechanism as a means of inducing wastewater reuse thereby increasing the life of the available water resource.

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PRICING FOR WATER SUPPLY;

ITS IMPACT ON SYSTEMS MANAGEMENT

INTRODUCTION

Problems related to water supply have become increasingly important in recent years. In the past, water has been so abundant that it was available in almost unlimited quantities. But this is no longer the case in most parts of the United States today. Water has become a resource that is relatively scarce. And the land, labor, and capital resources needed to convey water to places of useful application and to collect and treat wastewater are also scarce. To help deal with these problems, the National Water Commission was established by an Act of Congress and approved by the President on September 26, 1968. Its duties include reviewing national water resource problems, making projections for future needs, finding alternative ways of meeting these needs, considering economic and social consequences of water resource development, and advising on specific water resource matters.

If a resource is scarce, society must apportion its use so that it yields the maximum beneficial return. The Commission, in its draft report[13] has concluded that the limited supply of usable water should be rationed among its most important and productive uses, where it will have maximum utility for society. The pricing mechanism is a powerful and remarkably effective way to do this.

The rationale behind the pricing mechanism is based on the assumption that the more units consumed of any commodity, the less valuable is the last unit consumed. Thus, as the amount of water used by a consumer increases, the value of the last drop he uses decreases. The phenomenon is referred to by economists as "diminishing marginal utility."

When a price tag is attached to water, each consumer will continue to use more and more until its value to him just equals the price he is charged. When the price of water exceeds its value to the consumer, he will stop using it. The value of other goods and services that the consumer can command with his limited financial reserves begins to exceed the value of the extra units of water.

But those whose use of additional water continues to yield a return or utility in excess of the cost of the additional water will use more. Thus, water use will be shifted where it is most productive in terms of aggregate utility to society.

Congress has directed the National Water Commission to consider conservation and more efficient use of existing supplies as an alternative way of meeting future water requirements.[11] Though other means might be employed to motivate better use of existing and future supplies of water (elaborate rationing mechanisms based on input-output analysis, for example), nothing is as simple, comprehensive, and effective as the pricing mechanism.

This paper examines some of the work done by other investigators who have studied the interactions between pricing and water consumption. One objective is to verify and confirm some of the contentions made by these investigators that relate price and consumption of water, and that relate the cost of water supply to various physical factors in the system. Another aim is to examine the effect of pricing on design parameters for water supply systems and its possible effect on the design of wastewater reuse systems. Data used in this analysis was taken from the Community Water Supply Survey conducted by the Bureau of Water Hygiene in the summer of 1968. But before this data is discussed, a brief examination of the history and current status of water supply systems will be useful.

HISTORY OF WATER SUPPLY

Historically, water supply and wastewater disposal have their roots in antiquity, where the design, construction, and management of public water supplies and wastewater disposal systems were allied to the growth of capital cities and religious or trade centers. Developed as installations of considerable magnitude and complexity, their remnants still stand as monuments to sound yet daring feats of early engineering. A notable example among the great structures of ancient times are the aqueducts and sewers of Rome and her colonies.[4]

The sanitary control of water supplies and wastewater is of recent origin and is associated with the growth of cities during the industrial revolution of the 19th century. The scientific discoveries and engineering inventions of the late 18th and early 19th centuries paved the way for the creation of centralized industries to which people flocked for employment. As a result, the community facilities of the mushrooming industrial cities became overtaxed, and the need for the abundant distribution of safe water and for the effective disposal of

human excrement and other wastes became imperative. Water was often drawn from polluted rivers or from shallow wells in crowded sections of the community and distributed in courtyards by standpipes on intermittent days. The fatigue associated with fetching water was so great that the inhabitants only used it when absolutely necessary or for cooking; they rarely used much for washing clothes or personal hygiene.

Much of the water used for domestic purposes was of questionable quality, and waterborne disease outbreaks became common. To combat the growing disease problem, the science of sanitary engineering was born, and with it, the design and construction of the precursors of modern water supply systems.

CURRENT STATUS

Today, water is supplied to municipalities for drinking and culinary uses, bathing and washing, heating and air-conditioning systems, watering of lawns and gardens, recreational use in swimming and wading pools, numerous and varied industrial processes, and protection of life and property against fire. To provide for these varying uses, which average about 700 gallons per dwelling unit per day, the supply of water must be satisfactory in quality and adequate in quantity, readily available to the user, relatively cheap, and easily disposed of after it has served its purposes. The engineering systems that serve these multipurpose objectives are the water-works or water-supply system, and the wastewater works, or wastewater collection and disposal system.

The water supply system collects water from its natural sources, purifies it if necessary, and delivers it to the consumer The wastewater system collects sewage or used water from the community--about 70 percent of the water supplied, together with varying amounts of ground and surface water that enters the system. Surface runoff resulting from rainstorms and melting snow and ice is either collected by a system of drains that also carries away residential and industrial wastewater (combined sewerage) or collects the runoff separately in an independent or separate system of storm drains (separate sewerage). The collected sewage or wastewater is often discharged, after suitable treatment, into a natural drainage channel, a receiving body of water, or, on occasion, onto land. Often the same body of water serves both as a source of water and as a recipient of sewage and storm drainage. It is this multiple use of water that establishes the most important reason for water sanitation. Pollution of water by waste sources makes the water unsightly and malodorous and has the potential of adding disease-producing organisms to water supplies.

There are many interactions between municipal water supplies and wastewater treatment systems. These interdependencies grow more important as a region becomes more urbanized. The connecting link between the water supply and wastewater disposal systems is the plumbing system or system of water supply and wastewater collection within dwellings, commercial establishments, and industries.

Water supply systems are generally composed of (1) collection works, (2) purification works, where needed, and (3) transportation and distribution systems. The collection works either tap a source of water that is adequate in quantity to satisfy present and reasonable future demand on a continuous basis, or they convert an intermittent source into a continuous supply by storing surplus water for use during periods of low flows. If the water is not of satisfactory quality at the point of collection, purification works treat it: Polluted water is disinfected; esthetically unattractive or unpalatable water is treated to make it attractive and palatable; water containing iron or manganese is subjected to deferrization or demanganization; corrosive water is stabilized chemically; and excessively hard water is softened. The transportation and distribution works convey the collected and treated water to the community, where it is distributed to consumers. The amount of water delivered is often measured so that a charge can be made for its use.

Municipal supplies may be drawn from a single source or from a number of different sources. The water from multiple sources is ordinarily mixed before distribution.

BASIC PRINCIPLES OF PRICING

In a competitive economy, the forces of demand and supply, acting through the impersonal and automatic market mechanism, determine prices. These serve as proper guides to potential users and producers in their consumption, production, and investment decisions, since prices are based on the proper balance of a consumer's valuation of a product against its costs. Hence, prices automatically vary with changes in value and cost, and resources are directed to their "best" uses.

In some sectors of the economy, such as with public utilities, prices are not determined by the impersonal forces of the market. Instead, they are set by the pricing policies of utility managers. To retain the attributes of efficiency that are associated with competitive prices, these utility rates should be varied with changes in the demand and cost conditions facing the utilities. Even when a utility is producing a single product in a physical sense, there will

be variations in supply and demand conditions that are associated with the quantity of the product consumed during different times and at different locations. Therefore, for purposes of setting prices that reflect incremental, not historical costs, it is necessary to distinguish between products consumed at different locations and times. Although products might be physically similar, they are economically distinct and must be treated separately if they are to be efficiently priced.

One of the most important dimensions of supply and demand is temporal and will be used for illustrative purposes in this section. There are other dimensions that can be discussed, but the basic principles that will be established here apply to those dimensions as well.[3]

When the quantity of a good demanded at any given price varies over time, a "peak-load problem" exists. The solution requires one to choose the "right" capacity and the "right" price structure, a choice that determines the level of output in each subperiod of the production cycle. In competitive markets, the peak-load problem is solved by prices that fluctuate over time to reflect changes in value and cost. Theater and motion picture houses charge more for performances during periods of peak demand (evenings and week-ends) relative to periods of off-peak demand (matinees and weekdays). Resort hotels have higher rates during peak seasons. Rental fees for recreational goods exhibit a similar pattern, and barber shops frequently charge more on Saturdays than on other days.

Even when nominal prices remain constant, real prices may vary, since the quality of service may be altered during peak-demand periods. For example, grocery store prices remain constant during the store hours, but queuing and congestion increase the cost of shopping during peak hours. The open-market solutions to the peak-load problem vary widely. Some competitors provide no service at off-peak, and some provide the same service as at peak but at a lower price. Others provide better service at off-peak, but charge peak prices. Possibly all three alternatives may be provided, each by a different group of competitors. All of these solutions are the results of responsive and flexible pricing in which incremental values are balanced against incremental costs. Thus real prices are lower in times of excess capacity and correspondingly higher in times of shortage.

The conventional solution to the peak-load problem by urban water utilities, which do not operate by the rules of the open market, is basically different from the foregoing examples. The problem is handled solely as one of supply management.

That is, peak-demand days are usually taken as given--they are not related to price--and supplies are adjusted to meet these "requirements," regardless of the incremental values and costs associated with doing so. Not much imagination is needed to realize that resort hotels following this planning procedure and not utilizing demand management strategies would soon find themselves facing bankruptcy. Demand management, or the alteration of demands through responsive pricing, is not considered as being within the range of a water manager's choice. Prices typically remain constant from season to season, and so resources are used inefficiently, and inequities are imposed on the utility's consumers.

Uniform water rates mask significant differences in the marginal costs of serving customers during different periods. If summer users want more water, additional capacity must be provided; whereas only the incremental costs of operating the existing system must be incurred for additional use. Summer water, in an economic sense, is significantly different from winter water: Summer water is high-cost water. By not varying water rates to reflect these cost differences, investments are larger than economically justified. That is, peak demands that are used to guide water utility investments are not appropriately restrained by prices that reflect the peak-load marginal costs.

The general public, as well as most utility managers, perceives uniform rates as being equitable, since the same price per unit of water is charged to all customers, regardless of when the water is consumed. Because of cost differences, however, uniform prices mask a subtle type of price discrimination. Winter consumers subsidize summer consumers, because the winter consumer is absorbing a portion of the capacity costs created by the summer consumer's demands. In many cases, this means that the inner-city consumer who has a small yard to irrigate and a relatively small summer peak demand subsidizes the more affluent suburban dweller who has a larger yard and a greater summer peak demand.

The efficient allocation of resources that would be obtained in an open-market competitive economy can be approximated by water utilities if water managers broadened their range of choice to include demand management. In short, to solve the peak-load problem in an efficient manner, the following principles must be applied: (1) if capacity is not fully utilized, the price should reflect operating costs with no contribution to capacity costs; and (2) if demand exceeds capacity at this price, the price should be adjusted upward to restrain demand to the capacity level. Therefore, if the same type of capacity serves all users, capacity charges should be levied only when capacity is fully utilized, so that these peak users bear the responsibility for defraying capacity costs. When the capacity

charges exceed the incremental costs of capacity, investments in capacity are justified; whereas the reverse case would indicate that existing capacity is excessive. (This investment rule is for constant-cost conditions and would have to be modified slightly for decreasing or increasing costs.[3])

PRICING OF WATER SUPPLIES

Current Practice

Present water pricing is far from the ideal desired for an effective pricing system. Pricing by public agencies is typically based on revenue considerations, since the primary aim is a balanced budget and customer satisfaction. Pricing to provide efficient checks and balances on resource allocation is not given very high priority and is commonly below the cost of amortizing and operating a water supply system. Funds are usually sought elsewhere to make up the difference.

Self-supplied users, who account for about 80 percent of all water withdrawals (54 percent by industry, mostly for cooling; 23 percent for self-supplied irrigators; and 1 percent for rural supplies other than irrigation[10]), usually pay no price. However, they do generally bear the full costs of their own diversion and delivery systems and thus have, in effect, an internal price equal to costs of obtaining supply. Users of water, public or private, are now typically awarded a right to divert and use water free of charge; they, therefore, need pay no attention to values that some other use of the water might yield. Furthermore, only infrequently do means exist for the sale of water rights to bring about a reallocation of its uses. As a result, withdrawals from the natural water system are not always allocated to the uses that can yield the highest return.

The ability to apply refined pricing systems to the total supply is limited, since pricing of self-supplied water to reflect opportunity costs of water would require legislation that not only adopts a policy in favor of pricing, but also establishes entities to levy and collect charges.[1] Nevertheless, existing municipal and industrial supplies controlled by a water service agency can be subjected to improved pricing policies.

Influence of Pricing on Municipal Water Use

There is strong evidence that metering and pricing have substantial impacts on water use. Introduction of metering, for example, reduced water use by 36 percent in Boulder, Colorado.[2] Reductions ranging from 20 to 50 percent have been achieved in

other areas by metering,[13] which accomplishes two things. First, users are made aware of the extent of their water use. Second, water charges are, in effect, changed from a flat-rate system of pricing to rates based on incremental use. Both the information and the financial incentive are important in achieving reduction in water use.

The effect of pricing on water use is highly dependent on local conditions, including the pattern of water use. Studies show, for example, that a 10-percent increase in price may affect a reduction in overall use as great as 12 percent or as little as zero change. In Chicago, a recent study showed that price changes had no significant impact on use in the central city but did significantly affect suburban use.[14] The reductions that are achieved may not be long term, for as real incomes rise, consumption may start to rise again. Nevertheless, the need for expanding supply is postponed for a while.

Response to price changes varies with the type of water use. A 1964 survey of urban areas over 25,000 population indicated a weighted average water use pattern of 42 percent residential use, 21 percent commercial, 20 percent industrial, and 17 percent public use (public institutions, street cleaning, etc.).[5] Commercial establishments, including laundries and car washes, are ordinarily responsive to prices charged. Pricing response for manufacturing water use is highly variable, depending on the industry and plant design. Since the major component of industrial use is for cooling purposes (a low-value use), higher prices would probably have a significant impact. Residential water use is extremely important in most metropolitan areas, because it is not only a major use but is generally the greatest contributor to peak demands on the supply system. Table I indicates that residential use, primarily lawn sprinkling, may be many times greater on the peak summer day than the average through the year.

Residential water use may be divided into in-house or domestic use and lawn sprinkling. The most comprehensive study of price effects on residential use was carried out by a Johns Hopkins University study group in the early 1960's.[6] Price effects, as Table II indicates, were found to vary by type of use and by region of the country.

These data indicate that though the effect of price on use within a household may be expected to be modest, there is a significant effect on sprinkling uses, particularly in the eastern part of the country. Hanke found that the metering effect in Boulder resulted in (1) significant reductions in the amount of water used, (2) increased attention to water leakage, and (3) even a reduction in the area of yard sprinkled.

Table I. SUMMARY OF RESIDENTIAL WATER USE*

Type of study area	Average annual use†	Average maximum daily use†
Metered public water and public sewers:		
Western states (10 areas)	458	979
Eastern states (13 areas)	310	786
Metered public water and septic tanks (5 areas)	245	726
Flat-rate public water and public sewers (8 areas)	692	2,354
Apartments (5 areas)	191	368
Total (41 areas)	398	1,096

*Source: Linaweaver, F. P., Jr., et al. "A Study of Residential Water Use," 1967, HUD TS-12, U. S. Government Printing Office, Washington, D. C.

†Gallons per day per dwelling unit.

Table II. EFFECT OF PRICE ON RESIDENTIAL WATER DEMANDS, 1963-65

Type of use and area	Percent reduction in use after a 10-percent price increase
Domestic	2
Sprinkling	11
Western states	7
Eastern states	16

As noted in Table I, water use in apartments is lower than in detached homes. Similarly, seasonal variations that are due to sprinkling demands are less for apartments. Therefore, increases in water prices will have much less impact on the water use of established apartment areas. However, there is some evidence that increasing water rates results in greater use of modified water-using equipment (toilets, showers, and washing machines that use less water than the unmodified versions). The installation of meters and significant increases in water prices can be expected to lead to some water-saving practices through the installation of water-saving equipment and improved maintenance programs.

The practice of using "declining block" water pricing is widespread in metropolitan areas: The more water a user consumes, the less he pays per unit. This practice of promotional pricing can encourage inefficient water use. For example, in some areas, declining block pricing policies actually permit suburban users to pay less per unit of water for lawn sprinkling at times when they are burdening the supply system with the most costly peak demands. In such a situation, prices are lowest when marginal costs are highest. The installation of meters and the use of cost-based pricing policies will lead to (1) more efficient use of presently developed water supplies, and (2) the deferral of increasingly costly investments for development of new supplies.

Verifying the Conclusions Through Data Analysis

To verify some of the conclusions reached by Hanke and others with regard to the effect of pricing on the consumption of water, an analysis has been performed on data collected from EPA's Community Water Supply Survey (CWSS).[9] This survey was initiated in February 1969 by the Bureau of Water Hygiene of the U. S. Public Health Service (now the Water Supply Research Laboratory and the Water Programs Division of EPA) in cooperation with state and local health departments and the water utilities. This study had two purposes: (1) to determine whether or not the quality of the American consumers' drinking water met the 1962 U. S. Public Health Service Drinking Water Standards, and (2) to determine the nature and reliability of these water supply systems.

The study was designed to assess drinking water quality in urban areas in each of the regions of the Department of Health, Education, and Welfare (DHEW). Study areas were selected to give examples of the several types of water supplies in the country. The whole Standard Metropolitan Statistical Area (SMSA) was the basis of the study, with assessments made of all public water supplies in each study area. This coverage allowed an assessment of the drinking water quality of the large central

city, the suburbs, and the smaller communities located in the counties in the SMSA and of the interaction between them. The SMSA's studied in each DHEW Region were: Region I, State of Vermont; Region II, New York, N. Y.; Region III, Charleston, W. Va.; Region IV, Charleston, S. C.; Region V, Cincinnati, O., Kentucky, Indiana; Region VI, Kansas City, Mo., Kansas; Region VII, New Orleans, La.; Region VIII, Pueblo, Colo.; Region IX, San Bernadino, Riverside, and Ontario, Calif.

Each water supply was investigated using two criteria: (1) the water quality delivered to the consumer, and (2) the nature and adequacy of the water supply system itself. The drinking water quality was determined by sampling the finished and distributed water and returning these samples to the laboratories of the Bureau of Water Hygiene for physical, bacteriological, and chemical analyses. The nature and adequacy of the water supply system was determined by evaluating five items, where applicable: (1) source(s), (2) treatment, (3) distribution system, (4) operation and operators, and (5) surveillance program. This evaluation was accomplished by a field inspection of the supply system and the gathering of data on three standard forms. In addition, water quality data for the previous year was obtained from state and county health department records. When these investigations were completed, each water supply was rated either as excellent, good, fair, poor, or unfit to drink.

In addition to information related to the quality of service, data was collected on the cost of operation and quantities of water consumed. It is this data that has been analyzed using the Cincinnati SMSA as an example.

The Cincinnati SMSA--

The Cincinnati SMSA includes Dearborn County in Indiana, Boone, Campbell, and Kenton Counties in Kentucky, and Clermont, Hamilton, and Warren Counties in Ohio. Data were collected as a part of this survey on 67 public water supplies, including 57 community water supplies (those that piped water to homes) and 10 special water supplies (those that served institutions, trailer parks, and water haulers).[9] Twenty-two of these community water supplies were analyzed to relate factors affecting the cost of water delivered to the consumer to physical factors, and the price of the consumer's water to his utilization. Table III summarizes the statistics for the water supplies selected for analysis.

Two approaches were attempted in the analysis of the data. The first analysis was conducted in an attempt to determine the factors that relate the cost of water supply systems to the cost of supplying the finished product. In this case,

Table III. SUMMARY OF DATA FROM WATER SUPPLIES SELECTED FOR ANALYSIS

City	Pop. served (1)	Central city pop. density (persons/m^2) (2)	Average daily demand (10^6 gal) (3)	Water supplier* (4)	Water source† (5)	Quality indicators‡ Q_1 (6)	Q_2 (6)	Cost/ base price ($/1,000 gal) (7)	Per capita income (8)	Average water use (gal/ capita/ day) (9)
Cincinnati	850,000	6,569.3	112.60	1	1	1	1	0.35	$ 3,141	132
Franklin	11,000	4,166.8	1.50	1	0	1	0	0.45	2,813	136
Indian Hill	4,526	255.0	1.80	1	0	1	1	0.65	10,268	120
Norwood	31,000	11,526.7	4.00	0	1	1	1	0.30	3,148	129
Reading	15,000	4,752.6	1.85	1	0	1	0	0.40	3,171	123
Campbell	44,000	3,942.9	2.43	0	1	1	1	0.70	2,796	55
Covington	64,000	10,062.7	5.46	1	1	1	0	0.90	2,476	85
Florence	15,000	2,012.8	0.75	0	1	1	1	1.30	3,441	50
Newport	30,070	10,739.3	3.39	1	1	1	1	0.75	2,308	97
Harrison	5,140	4,308.9	0.36	1	0	1	0	0.70	2,902	71
Lebanon	6,500	4,308.9	1.05	1	0	0	0	0.30	3,093	162
Loveland	5,000	2,276.4	0.57	1	0	1	0	0.50	2,925	76
Mason	6,200	1,524.8	0.25	1	0	1	1	1.15	3,159	40
Wyoming	10,000	2,865.2	0.90	1	0	1	1	0.80	5,974	90
Aurora	6,300	168.7	0.517	1	0	1	0	0.85	2,710	82
Lawrenceburg	5,200	2,382.9	0.25	1	0	1	0	0.70	2,639	48
Ludlow	6,010	8,904.3	0.335	0	1	1	0	0.40	2,590	55
Glendale	3,000	1,660.6	0.30	1	0	1	0	0.70	4,778	100
Milford	4,530	4,131.0	0.44	1	0	1	0	0.55	3,296	97
South Lebanon	2,720	4,533.3	0.32	1	0	0	0	0.20	2,544	118
Williamsburg	2,200	1,656.2	0.10	1	1	1	0	1.15	3,543	45
Highland Heights	4,000	2,909.2	0.13	0	1	1	1	0.70	4,225	32

*1 = Primary source; 0 = secondary source.
†1 = Surface supply; 0 = ground supply.
‡1,1 = Good; 1,0 = fair; 0,0 = poor.

the data in Columns 2 through 8 were regressed against the data in Column 9. The second analysis is an attempt to relate the price of water to consumption, and the data in Columns 9 and 10 were regressed against the data in Column 11. The cost analysis will be discussed initially.

Cost Analysis--The variables in this analysis are defined as follows:

- C = the base cost in dollars per 1,000 gal. of water;
- P_s = the population served by the water utility;
- P_D = the population density in persons per square mile for the service area;
- D = average daily demand for water in millions of gallons;
- S_p = supplier of water, where $S_p = 1$ implies that the utility is the primary supplier of water, and $S_p = 0$ implies that the utility is a secondary supplier;
- S_o = source of the water the utility supplies, where $S_o = 1$ implies that the utility uses surface water, and $S_o = 0$ implies that the utility uses ground water; and,
- Q_1 and Q_2 are dummy variables indicating the rating of the water utility, where $Q_1 = 1$, $Q_2 = 1$ implies a rating of good, $Q_1 = 1$, $Q_2 = 0$ implies that the rating is fair, and $Q_1 = 0$, $Q_2 = 0$ implies that the rating is poor.

The analysis is static or cross-sectional; time variations are not considered, but several points in the same period are studied. By this approach, changes over time can be ignored, and the differences between places can be emphasized. In addition, by choosing a single metropolitan area, differences in the price level of equipment, labor, and capital are emphasized.

Using a step-wise regression analysis, we obtain the following equation:

$$C = \underset{(1.582008)}{0.00000944\ P_s} - \underset{(-4.2185103)}{0.00005972\ P_D} - \underset{(-1.73036672)}{0.07722744\ D}$$

$$+ \underset{(3.1656385)}{0.42094866\ S_p} + \underset{(3.352057)}{0.47268092\ S_o} + \underset{(1.95385515)}{0.26372458\ Q_1}$$

$$+ \underset{(1.66660721)}{0.15042853\ Q_2} + 0.1024940 \qquad \ldots\ (1)$$

The multiple correlation coefficient for this equation is approximately 0.81, which means that nearly 66 percent of the variation of the data is explained by this equation. The t values for each variable are shown in parentheses below that variable. Based on this analysis, it is apparent that such variables as population density, whether or not the utility is a secondary or primary supplier, and the source of water play the primary roles in determining the cost of a water supply system. Total population served, total demand, and quality of the system play secondary roles.

In Equation 1, as population density decreases (negative value), cost per 1,000 gal. increases proportionally. This implies significant economies of scale with density and is consistent with the findings of other investigators. As might be expected, the cost of the supply is influenced by the source of water. Surface supplies are the most expensive, no doubt because of the storage required when surface water is used. Most interesting is the significance of the supply variable S_p, which indicates that secondary suppliers charge less for water than the utilities from which they buy it. This practice appears to be contrary to common sense until one examines the management practices among water utilities. Large users of water commonly receive discounts, and such is apparently the case in this analysis. The small utilities that buy water from the large utilities pay less per unit for their water than the large utilities' individual consumers. The small utilities then pass this discount along to their own customers.

Price Versus Consumption--In this analysis, data from Table III, Column 9, were regressed against data from Column 11, with price as the independent variable and consumption as the dependent variable. Several different models were used in an attempt to relate price (cost per gallon) versus consumption (gallons per capita per day). The models examined were as follows:

- Linear: Y versus X;
- Log-Log: LnY versus LnX;
- Inverse: Y versus 1/X;
- Semi-Log: LnY versus X; and,
- Inverse Semi-Log: LnY versus 1/X.

In the following equations, P = price, and C = consumption. The t statistic is given in parentheses below the independent variable, and R^2 is given for each equation. The equations are as follows:

- Linear: $C = -85.32896P + 144.5577$, $R^2 = 44.512$ . . . (2)
  (-4.2244442)

- Log-Log: $\ln C = -0.6019963 \ln P + 1.7718307$,
  (-3.7609605) $R^2 = 38.497$ . . . (3)

- Inverse: $C = 22.605648/P + 45.714695$, $R^2 = 37.751$ . . (4)
  (3.7061572)

- Semi-Log: $\ln C = -0.4348467P + 2.1947295$,
  (-3.8130064) $R^2 = 39.199$ . . . (5)

- Inverse Semi-Log: $\ln C = 0.1129775/P + 1.6934253$,
  (3.257656) $R^2 = 31.400$ . . . (6)

There is little to indicate that one model yields superior results when compared to another. Price elasticity of demand when calculated from the Log-Log model is -0.602. When calculated by expanding around the mean of the linear model, price elasticity is:

$$\varepsilon = \frac{dQ}{dP} \cdot \frac{P}{Q}$$

$$\varepsilon = -85.33 \left(\frac{0.66}{88.32}\right)$$

$$\varepsilon = -0.63$$

Both of these results are consistent with each other and with intuition. These elasticities indicate that water consumption is inelastic ($\varepsilon < 1$) but that they are significantly different from zero. By increasing the price by 10 percent, consumption would be expected to be reduced by 6 to 6.3 percent. These results are consistent with those reported by Hanke; but more importantly, they are based on data that have been accumulated directly from municipal water supplies in a cross-sectional study. The consumption patterns in this metropolitan area should have reached steady state as opposed to Hanke's work and should, therefore, reflect the true reaction of the consumer to price.

To extend this analysis, income per capita (Column 10 in Table III) is added as an independent variable to Equation 2 in the analysis above. If I = per capita income, the following relationship results:

$C = -87.688024P + 0.0042987I + 130.882474$, $R^2 = 46.097$ . . (7)
(-4.385257) (1.2601998)

From this analysis, it appears that per capita income has little effect on the consumption of water. This may be true for a cross-sectional analysis, but over time and over a broader geographical area, per capita income may be significant.

PRICE AND ITS IMPACT ON TECHNOLOGY

The impact of the price of water on water supply design is extremely important. Linaweaver[8] developed a design equation based on expected average domestic water use, irrigable land, potential evapotranspiration, and potential precipitation. This equation is as follows:

$$\bar{Q} = \bar{Q}_d + 0.6\ c\ a\ \bar{L}_s(\bar{E}_{pot} - \bar{P}_{eff})$$

where:

$\bar{Q}$ = expected average demand for any period expressed as a rate in gallons per day;

$\bar{Q}_d$ = expected average domestic (household) use in gallons per day, which applies for all periods of a day or longer and may be reliably estimated from a simple function of the average market value of dwellings as described below;

0.6 = a coefficient to adjust for the difference between actual evapotranspiration from lawns and potential evapotranspiration;

c = constant to adjust for units, 2.72×10^4 gal. per acre-inch of water;

a = number of dwelling units;

$\bar{L}_s$ = average irrigable area in acres per dwelling unit;

$\bar{E}_{pot}$ = estimated average potential evapotranspiration for the period of demand in question in inches of water per day; and,

$\bar{P}_{eff}$ = amount of natural precipitation effective in satisfying evapotranspiration for the period and thereby reducing the requirements for lawn sprinkling in inches of water per day.

The principal quantity considered for design is the expected maximum daily demand, which is likely to occur during the latter part of June or during July, when high temperatures and long hours of sunlight combine to make a high evapotranspiration. Typical values can be assumed for the constants in Linaweaver's equation. These are listed as follows:

$$c = 2.72 \times 10^4$$

$$\bar{E}_{pot} - \bar{P}_{eff} = 0.20$$

$$\bar{L}_s = 0.28$$

$$Qd = 244$$

$$Q_{max} = 1{,}160 \text{ gpd per dwelling unit}$$

If a 10 percent increase in price is assumed based on the previous analysis, a 6 percent decrease in consumption would be expected. However, this price elasticity is based on the mean value for consumption, and it is likely that the reduction in consumption for lawn sprinkling and other uses have a greater price elasticity than 6 percent. Hanke shows a price elasticity of 1.12 for residential sprinkling. If the price elasticities were separated and the 6 percent figure were applied to Qd and the 11.2 percent to the sprinkling demand in Linaweaver's equation, a reduction would occur in Q_{max} to a value of 1,043 gpd.

If this change in the demand for system capacity were actually to take place with an increase in price, it would be expected to cost the consumer more money, since the data show that the situation is relatively inelastic. However, it also has some long-term benefits, since it would also increase the life of existing water resources and save in long-term capital investment. Additional research might be fruitful on these types of trade-offs.

PRICING AND ITS IMPACT ON WATER REUSE

The problem of supplying water for municipal use is becoming increasingly difficult in the United States, and this trend is expected to continue in the foreseeable future. According to recent estimates of the Water Resources Council, several regions in the United States may experience critical problems of water shortage and water quality deterioration unless suitable measures are taken. Under certain conditions, the optimal solution to increasing municipal demands and reducing water quality deterioration may rest with wastewater renovation. Advanced waste treatment could lower the amounts of pollutants discharged to prescribed levels, and the resultant high quality effluent could be made available on site for municipal use.[7]

The use of renovated wastewater provides an additional source of water supply, but it provides what would be termed an engineering solution to the problem. Municipal demands could also be met more effectively by changing the way in which

water is used. This can be accomplished by reducing the amount of water used or altering demands, as has been discussed earlier.

Reduction in use could be accomplished by metering or pricing policies, use restrictions, or recycling. Both metering and pricing policies have been found to be an effective means of lowering municipal water demands, although they are not (at this time) employed by water managers for this purpose. Several major cities, including New York and Chicago, do not meter their water supplies but instead, charge a flat rate. The practicability of metering must be evaluated according to the costs of installation and operation versus the increased supply that would be available as the result of their installation. One study discussed earlier indicated a 40 percent drop in per capita water consumption in Boulder, Colo., from 1960, when only 5 percent of the city was metered, to 1965, when the city was fully metered. Another study indicated that the quantity demanded for residential uses, particularly sprinkling, is affected by the price charged. It has been suggested that even maximum-day demands respond to price changes, a fact that could be used by management for altering average and maximum-day demands.

The new Federal Water Pollution Control Act requires that no pollution be discharged to the Nation's streams by 1980. The achievement of this goal will be extremely expensive, and the quality of effluent that might result will be extremely high. It makes sense, therefore, from an engineering point of view, that these effluents be recycled for municipal use. If economic measures (pricing) were applied to the original drinking water stream reaching the consumer, the amount of domestic water consumed and, therefore, the amount of water discharged to be treated, will be reduced. These lower effluent quantities will have higher concentrations of pollutants, a situation that will have an impact on the kind of technology used for treatment. The higher concentrations of waste will probably make the treatment process more efficient. At any rate, by introducing a pricing policy for water, there should be substantial changes in technology. These changes may actually reduce treatment, collection, and distribution costs.

This approach will tend to make the cost of water supply and sewage services explicit and, hopefully, more efficient. At this point, these ideas are only speculation, but they provide some interesting thought for joint exploration by economists and engineers.

SUMMARY AND CONCLUSIONS

The current state of knowledge with regard to the pricing of water supplies and its impact on water consumption has been examined in some detail. Although considerable work has been done by economists in this area, little of the information generated has been used or possibly understood by practicing engineers. In an attempt to demonstrate that the idea of pricing is not a wild-eyed economic theory, engineering data collected by the EPA have been used to support the basic premise of pricing and its impact on water utilization. These data were then analyzed for their relation to the cost of supply and pricing for consumption, and some of the impacts that pricing might have on water supply technology were sketched. It was also suggested that the pricing of water supplies to reduce consumption could have a significant effect on the conservation of potable supplies.

Several obvious conclusions arise from this analysis:

- Pricing should be considered in conjunction with technology for the design of water supply systems.

- There are significant diseconomies of population density in water supply systems. That is, as densities decrease, the average per capita cost for water increases.

- Average price elasticities of demand for water are less than one but significantly greater than zero.

- The pricing mechanism could have a significant impact on water supply technology.

- Pricing should be considered in conjunction with technology when considering the issue of water reuse.

- Management practices in which a large utility gives discounts to smaller utilities leads to price discrimination against its own customers.

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